

Appendix A

APPENDIX A

The table below applies the terms of Applicant's new claims 23-26 to the disclosure of the present application, as required by 37 C.F.R. § 1.607(a)(5). All page citations are to the specification of the present application.

Claim Limitation	Disclosure In The Present Application
23. A method for determining a parameter of interest of a subsurface region of earth formations comprising:	<p>“The present invention involves use of a bottom hole assembly deployed in a borehole to estimate formation properties.” (Page 5.)</p> <p>“The present invention is a system and method to estimate formation properties and in particular to estimate pore pressure [an example of a parameter of interest] in the vicinity of or in the formation ahead of the drill bit by analyzing acoustic waves that are emitted from the bottom hole assembly (BHA) and which pass through and are reflected from the formation.” (Pages 6-7.)</p> <p>“The present invention also includes a method to estimate the pore pressure in the vicinity of the BHA. The method includes the steps of detecting actively or passively generated acoustic signals of varying frequencies, directly and after they are reflected from formations in the vicinity of the BHA, determining frequency dependent properties, such as attenuation or velocity, of the detected signals, and estimating the pore pressure of formations in the vicinity of and ahead of the BHA. If so desired, other properties of formations in the vicinity of and ahead of the BHA may also be estimated.” (Page 8.)</p>
(a) obtaining seismic survey information about the subsurface region;	<p>“Data presently used to estimate the pore pressure profile versus depth at proposed well locations include offset well data, surface seismic data, seismic-while-drilling data, and geologic models.” (Page 2.)</p> <p>“In the invention a source signal is emitted from the bottom hole assembly and at least one signal is received by one or more receivers in the bottom hole assembly.” (Page 6.)</p> <p>“The present invention is a system and method to estimate formation properties and in particular to estimate pore pressure in the vicinity of or in the formation ahead of the drill bit by analyzing acoustic waves that are emitted from the bottom hole assembly (BHA) and which pass through and are reflected from the formation. The acoustic waves used in the present invention are in the frequency range up to about 20 kHz and can be generated passively, such as by the drill bit in the drilling process, or actively by placing a controlled acoustic signal source in a</p>

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	<p>BHA.” (Pages 6-7.)</p> <p>“The method includes the steps of detecting actively or passively generated acoustic signals of varying frequencies, directly and after they are reflected from formations in the vicinity of the BHA, determining frequency dependent properties, such as attenuation or velocity, of the detected signals, and estimating the pore pressure of formations in the vicinity of and ahead of the BHA.” (Page 8.)</p> <p>“The depth of penetration of the source signals from the source to the reflectors will vary from several tens of feet when operating in a relatively high frequency range, from about 5000 Hz. and above, to several hundreds of feet when operating in a relatively low frequency range, from about 50 Hz. to 5000 Hz.” (Page 10.)</p>
<p>(b) identifying a plurality of interpreted seismic horizons of interest from the obtained survey information;</p>	<p><i>Figure 1 shows reflector 4, which is the boundary between a first formation 3 and a second formation 5. Reflector 4 is an interpreted seismic horizon of interest identified from obtained survey information.</i></p> <p>“Source signal 20 is emitted from a passive source, such as drill bit 14, or an active source (not depicted) in bottom hole assembly 12, and propagates through first formation 3 to reflector 4, which is the boundary between first formation 3 and second formation 5.” (Page 11; Figure 1.)</p> <p>“Seismic-while-drilling (SWD) is a method for estimating formation velocity above and below the drill-bit during the drilling process.” (Page 3.)</p> <p>“Compared to pore pressure prediction using surface seismic methods, the main advantages of SWD are that the depth to sub-surface reflectors is better constrained and vertical resolution is improved.” (Page 4.)</p> <p>“A second advantage is that the energy from the active source may be directed in specific directions ahead of the bit to increase the signal strength from the desired reflectors.” (Page 9.)</p> <p>“Whether a passive or an active source is used in the present invention, bed boundaries, heterogeneities and other rock properties cause changes in acoustic impedance which reflect some of the source signal energy back to the BHA and which the receivers will detect. The depth of penetration of the source signals from the source to the reflectors will vary from several tens of feet when operating in a relatively high frequency range, from about 5000 Hz. and above, to several hundreds of feet when operating in a relatively low frequency range, from about 50 Hz. to 5000 Hz. If the drill bit noise spectrum is used as the source,</p>

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	<p>the measured spectrum can be directly cross-correlated with the reflected signal to determine the time origin and the distance to the reflector. If an active source is used, techniques similar to those used in reflection seismology or ground-penetrating radar can be used to determine the distance to the reflectors.” (Pages 9-10.)</p>
<p>(c) obtaining estimated seismic velocities corresponding to at least one interval between at least one pair of said plurality of seismic horizons, wherein the obtained seismic velocities are selected from the group consisting of:</p>	<p>“Seismic-while-drilling (SWD) is a method for estimating formation velocity above and below the drill-bit during the drilling process.” (Page 3.)</p> <p>“The signal to be used to determine formation velocity is detected by cross correlating the signal propagating through the earth with the signal that has propagated along the drill string. See for example the disclosure of Staron, Arens, and Gros, in U.S. Patent No. 4,718,048 titled “Method of Instantaneous Acoustic Logging Within a Wellbore.” That signal is usually at a single frequency, typically about 50 Hz, and, using inversion processing, which is analogous to surface seismic processing, can be used to estimate the acoustic impedance and velocity of <i>intervals</i> below the drill bit.” (Pages 3-4 (emphasis added).)</p> <p>“The method includes the steps of detecting actively or passively generated acoustic signals of varying frequencies, directly and after they are reflected from formations in the vicinity of the BHA, determining frequency dependent properties, such as attenuation or velocity, of the detected signals, and estimating the pore pressure of formations in the vicinity of and ahead of the BHA.” (Page 8.)</p> <p>“A second advantage is that the energy from the active source may be directed in specific directions ahead of the bit to increase the signal strength from the desired reflectors.” (Page 9.)</p> <p>“Whether a passive or an active source is used in the present invention, bed boundaries, heterogeneities and other rock properties cause changes in acoustic impedance which reflect some of the source signal energy back to the BHA and which the receivers will detect. The depth of penetration of the source signals from the source to the reflectors will vary from several tens of feet when operating in a relatively high frequency range, from about 5000 Hz. and above, to several hundreds of feet when operating in a relatively low frequency range, from about 50 Hz. to 5000 Hz. If the drill bit noise spectrum is used as the source, the measured spectrum can be directly cross-correlated with the reflected signal to determine the time origin and the distance to the reflector. If an active source is used, techniques similar to those used in reflection seismology or ground-penetrating radar</p>

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	can be used to determine the distance to the reflectors.” (Pages 9-10.)
(i) S-wave velocity data generated from normal moveout (NMO) velocity analysis,	<p>“In the present invention acoustic detectors are mounted along the BHA to detect both compressional [P] and shear [S] waves.” (Page 7.)</p> <p>“Preferably, receivers used in the present method should be capable of measuring both compressional [P] waves and shear [S] waves.” (Page 10.)</p> <p>“It will be understood that in a preferred embodiment of the present invention receivers 16 can sense both compressional [P] and shear [S] waves.” (Page 11.)</p> <p>“For example, formation velocity estimation from seismic data using <i>normal moveout analysis</i> techniques is well understood in the art.” (Pages 2-3 (emphasis added).)</p> <p>“Because receivers 16 are positioned at varying distances from the source, the establishment of the arrival time of reflected signal 28 at each receiver allows the distance from source 14 to boundary 4 to be determined using <i>normal moveout methods</i>. As will be understood those skilled in the art, normal moveout methods are also used in surface seismic surveys. Reflected signal 28 will be identified by hyperbolic move out, and will provide the frequency dependent information from which embodiments of the method of the present invention allow the estimation of the pore pressure in second formation 5.” (Page 13 (emphasis added); Figure 1.)</p>
(ii) P-wave velocity data from VSP look-ahead inversion, and (iii) S-wave velocity data from VSP look-ahead inversion;	<p>“In the present invention acoustic detectors are mounted along the BHA to detect both compressional [P] and shear [S] waves.” (Page 7.)</p> <p>“Preferably, receivers used in the present method should be capable of measuring both compressional [P] waves and shear [S] waves.” (Page 10.)</p> <p>“It will be understood that in a preferred embodiment of the present invention receivers 16 can sense both compressional [P] and shear [S] waves.” (Page 11.)</p> <p>“Increased seismic data resolution can be achieved by employing Vertical Seismic Profiling (VSP). In VSP, geophones are lowered into the borehole so that the precise depth of the geophone is known and only the one way seismic travel times need to be measured.” (Page 5 (emphasis added).)</p> <p><i>The specification is replete with passages that disclose obtaining look-ahead velocity data, including inversion processing of such data. The following passages are exemplary:</i></p>

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	<p><i>Figure 1 and its corresponding description disclose a bottom hole drilling assembly that is used to obtain velocity data from acoustic waves that are reflected by reflector 4, which is ahead of the assembly.</i></p> <p>“Seismic-while-drilling (SWD) is a method for estimating formation velocity above and <i>below the drill-bit</i> during the drilling process.” (Page 3 (emphasis added).)</p> <p>“The signal to be used to determine formation velocity is detected by cross correlating the signal propagating through the earth with the signal that has propagated along the drill string. See for example the disclosure of Staron, Arens, and Gros, in U.S. Patent No. 4,718,048 titled “Method of Instantaneous Acoustic Logging Within a Wellbore.” That signal is usually at a single frequency, typically about 50 Hz, and, using <i>inversion</i> processing, which is analogous to surface seismic processing, can be used to estimate the acoustic impedance and <i>velocity of intervals below the drill bit.</i>” (Pages 3-4 (emphasis added).)</p>
<ul style="list-style-type: none"> (d) calibrating the estimated seismic velocities to the parameter of interest; and (e) using the results of said calibration and the obtained seismic velocities to obtain the parameter of interest at any location within the seismic survey. 	<p><i>The specification contains numerous disclosures of calibrating estimated seismic velocities to a parameter of interest (e.g., pore pressure) and using the results of this calibration and the obtained velocities to obtain the parameter of interest at any location in the survey. The passages cited below are exemplary:</i></p> <p>“Data presently used to estimate the pore pressure profile versus depth at proposed well locations include offset well data, surface seismic data, seismic-while-drilling data, and geologic models. Pressure measurements from nearby offset wells can provide the most accurate pre-drill pressure information, but for remote locations these data are generally not available. Pore pressure estimation from surface seismic data is based on an empirical relationship between the velocity of sound waves in the formation and pore pressure, with assumptions made for the nature of the formation, in other words the type of rocks that are expected to be present (which is also referred to as formation lithology). This relationship is based on a number of different properties which are understood in industry. For example, formation velocity estimation from seismic data using normal moveout analysis techniques is well understood in the art. Equally well understood is the fact that formation velocity is a function of both the elastic moduli and the density of the rock, and that formation velocity generally increases with depth as rocks become more and more compacted. It is also understood that an increase in pore pressure with depth often coincides with a decrease in this increasing velocity trend (or even an actual decrease in velocity with depth)</p>

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	<p>because the higher pore pressure is associated with less compacted rock. These combined factors allow derivation of empirical velocity-pore pressure relationships for use with seismic data.” (Pages 2-3.)</p> <p>“The signal to be used to determine formation velocity is detected by cross correlating the signal propagating through the earth with the signal that has propagated along the drill string. See for example the disclosure of Staron, Arens, and Gros, in U.S. Patent No. 4,718,048 titled “Method of Instantaneous Acoustic Logging Within a Wellbore.” That signal is usually at a single frequency, typically about 50 Hz, and, using inversion processing, which is analogous to surface seismic processing, can be used to estimate the acoustic impedance and velocity of intervals below the drill bit. Pore pressure is then estimated using the same velocity-pore pressure empirical relationships used with surface seismic data.” (Pages 3-4.)</p> <p>“The pore pressure estimate for the formation ahead of the drill bit can be derived from the analysis of the frequency dependence of both the compressional wave amplitudes in the reflected signals and the change in velocities of the received signals. In addition, pore pressure may be estimated from the change in the ratio of the compressional to the shear wave velocities in the received signals. Other formation property estimates may also be derived from the analysis of the acoustic waves, such as fluid properties and permeability.” (Page 7.)</p> <p>“The present invention also includes a method to estimate the pore pressure in the vicinity of the BHA. The method includes the steps of detecting actively or passively generated acoustic signals of varying frequencies, directly and after they are reflected from formations in the vicinity of the BHA, determining frequency dependent properties, such as attenuation or velocity, of the detected signals, and estimating the pore pressure of formations in the vicinity of and ahead of the BHA. If so desired, other properties of formations in the vicinity of and ahead of the BHA may also be estimated.” (Page 8.)</p> <p><i>Pages 17-19 contain the following detailed discussion of two embodiments of the invention by which pore pressure (a parameter of interest) and other properties can be estimated from frequency-dependent change in velocity and from the calculation of the ratio of the measured compressional wave velocity to the shear wave velocity:</i></p> <p>“A second embodiment of the method of the present invention allows estimation of pore pressure from the frequency-dependent change in velocity of the signals that</p>

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	<p>propagate back to bottom hole assembly 12. Several mechanisms have been proposed to account for the frequency dependent wave propagation properties of fluid filled porous rocks, including the Biot slow wave mechanism and the squirt flow mechanism. In either case, both a frequency dependent velocity as well as a frequency dependent attenuation will result, and both will vary with the pore pressure. Thus, an alternate approach for estimating pore pressure ahead of the BHA is to measure the velocity of the waves traveling through the formation and reflected back to the receivers on the bottom hole assembly as a function of frequency. Following practices which are understood in the geophysical industry, wave propagation velocities as a function of frequency can be determined from the time of arrival of the wave front at the receiver and the empirical-velocity-to-pore pressure relationships discussed above can then be used to estimate the pore pressure of the formation ahead of the BHA.</p> <p>“A third embodiment of the method of the present invention allows the estimation of pore pressure from the calculation of the ratio of the measured compressional wave velocity (v_p) to the shear wave velocity (v_s). Measured ultrasonic frequency data suggests that the ratio v_p/v_s increases by approximately 10% as the pore pressure increases from a negligible value up to the confining pressure. See for example, Christensen and Wang, 1985, “The Influence of Pore Pressure and Confining Pressure on Dynamic Elastic Properties of Berea Sandstone,” Geophysics, vol. 50, No.2, pp. 207-213. The Christensen and Wang data relate changes in the confining and pore pressures in a formation to the Poisson’s ratio. It will be understood to those skilled in the art that Poisson’s ratio can be directly calculated from the ratio of the compressional wave velocity to the shear wave velocity. Thus, in this embodiment of the method of the present invention, pore pressure may be estimated by analysis of the compressional and shear velocities of the received signals described above in conjunction with the Poisson’s ratio relationship to pore pressure data such as provided by Christensen and Wang for Berea sandstone.</p> <p>“It will be understood to those skilled in the art that use of this embodiment of the method of the present invention to estimate pore pressure from the ratio of compressional wave velocity to the shear wave velocity requires data, such as that provided by Christensen and Wang for Berea sandstone,</p>

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	<p>which corresponds generally to the nature of the rocks in the formation in which the bottom hole assembly is deployed. Analogous data for other rock types are available in the literature, for example see Hamilton, E.L., "Vp/Vs and Poisson's Ratios in Marine Sediments and Rocks," J. Acoustic Soc. America, V. 66, No. 4, Oct. 1979, pgs 1093-1101. In addition, Figure 4 shows data allowing this embodiment to be used for formations comprised of Labette Shale. In this plot the horizontal axis, effective stress 70, is the difference between the mean confining stress and the pore pressure. The left vertical axis indicates both the compressional wave velocity 72 (diamond symbol) and the shear wave velocity 74 (square symbol). The right vertical axis indicates the change in Poisson's Ratio 76 (triangle symbol) as the compressional and shear wave velocities change. Since receivers 16 may be used according to the present embodiment to measure both the compressional wave component of reflected signal 28 and the shear wave component of reflected signal 28, this data allows calculation of the velocity ratio and the estimation of pore pressure</p> <p>"Information on formation properties other than pore pressure may also be obtained with the invention disclosed herein. For example, lithology and fluid content are often estimated from compressional and shear wave signals. These estimates can be made from the signals that are detected and processed according to the present invention, thereby allowing estimation of these properties for the formation adjacent to and ahead of the BHA. In addition, it will be understood that compressional wave velocities may be used to estimate rock strength. Other formation properties that may be determined from the present invention will be known to those skilled in the art."</p>

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<p>24. The method of claim 23 wherein the obtained seismic velocities are S-wave velocity data generated from normal moveout (NMO) velocity analysis.</p>	<p>“In the present invention acoustic detectors are mounted along the BHA to detect both compressional [P] and shear [S] waves.” (Page 7.)</p> <p>“Preferably, receivers used in the present method should be capable of measuring both compressional [P] waves and shear [S] waves.” (Page 10.)</p> <p>“It will be understood that in a preferred embodiment of the present invention receivers 16 can sense both compressional [P] and shear [S] waves.” (Page 11.)</p> <p>“For example, formation velocity estimation from seismic data using <i>normal moveout analysis</i> techniques is well understood in the art.” (Pages 2-3 (emphasis added).)</p> <p>“Because receivers 16 are positioned at varying distances from the source, the establishment of the arrival time of reflected signal 28 at each receiver allows the distance from source 14 to boundary 4 to be determined using <i>normal moveout methods</i>. As will be understood those skilled in the art, normal moveout methods are also used in surface seismic surveys. Reflected signal 28 will be identified by hyperbolic move out, and will provide the frequency dependent information from which embodiments of the method of the present invention allow the estimation of the pore pressure in second formation 5.” (Page 13 (emphasis added); Figure 1.)</p>

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<p>25. The method of claim 23 wherein the obtained seismic velocities are P-wave velocity data from VSP look-ahead inversion.</p>	<p>“In the present invention acoustic detectors are mounted along the BHA to detect both compressional [P] and shear [S] waves.” (Page 7.)</p> <p>“Preferably, receivers used in the present method should be capable of measuring both compressional [P] waves and shear [S] waves.” (Page 10.)</p>
<p>26. The method of claim 23 wherein the obtained seismic velocities are S-wave velocity data from VSP look-ahead inversion.</p>	<p>“It will be understood that in a preferred embodiment of the present invention receivers 16 can sense both compressional [P] and shear [S] waves.” (Page 11.)</p> <p>“Increased seismic data resolution can be achieved by employing Vertical Seismic Profiling (<i>VSP</i>). In <i>VSP</i>, geophones are lowered into the borehole so that the precise depth of the geophone is known and only the one way seismic travel times need to be measured.” (Page 5 (emphasis added).)</p>

The specification is replete with passages that disclose obtaining look-ahead velocity data, including inversion processing of such data. The following passages are exemplary:

Figure 1 and its corresponding description disclose a bottom hole drilling assembly that is used to obtain velocity data from acoustic waves that are reflected by reflector 4, which is ahead of the assembly.

“Seismic-while-drilling (SWD) is a method for estimating formation velocity above and ***below the drill-bit*** during the drilling process.” (Page 3 (emphasis added).)

“The signal to be used to determine formation velocity is detected by cross correlating the signal propagating through the earth with the signal that has propagated along the drill string. See for example the disclosure of Staron, Arens, and Gros, in U.S. Patent No. 4,718,048 titled “Method of Instantaneous Acoustic Logging Within a Wellbore.” That signal is usually at a single frequency, typically about 50 Hz, and, using ***inversion*** processing, which is analogous to surface seismic processing, can be used to estimate the acoustic impedance and ***velocity of intervals below the drill bit***.” (Pages 3-4 (emphasis added).)